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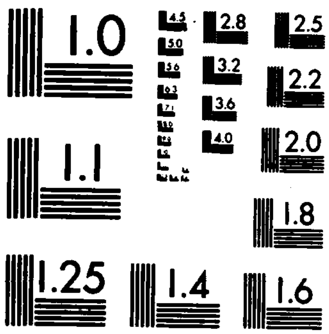

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this research is to see how surface roughness affects the hydrodynamic stability of a supersonic laminar boundary layer. This note summarizes work done in the second (1982-1983) year of the program. The outcome of the first year of the program had been to demonstrate the great resistance of the supersonic flow to destabilization and tripping by roughness, to choose a final roughness capable of such destabilization and tripping, and to complete boundary layer surveys on an axisymmetric body so roughened as a prerequisite to the stability measurements. In the present period the

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AFOSR-TR- 83-1287

ANNUAL PROGRESS SUMMARY
(10/82 - 9/83)

THE HYDRODYNAMIC STABILITY OF A SUPERSONIC LAMINAR BOUNDARY LAYER OVER A ROUGH WALL

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1. Background and Summary

The purpose of this research is to see how surface roughness affects the hydrodynamic stability of a supersonic laminar boundary layer. This note summarizes work done in the second (1982-1983) year of the program.

The outcome of the first year of the program had been to demonstrate the great resistance of the supersonic flow to destabilization and tripping by roughness, to choose a final roughness capable of such destabilization and tripping, and to complete boundary layer surveys on an axisymmetric body so roughened as a prerequisite to the stability measurements. In the present period the geometry was changed to a planar (flat plate) one to correct defficiencies found in the axisymmetric flow, which however uses the same roughness geometry as before. The flowfield measurements on this model have been completed, as have about 30% of the final stability measurements.

2. Experimental Activity

Work in the 1982-1983 period consisted of (a) fabricating the experimental models, (b) measuring the flowfield over the models, and (c) making the initial stability measurements. The basic model consists of a 22.4 x 7.9 cm. flat plate whose surface can change from a smooth to a rough one by the use of suitable inserts. The rough insert used had a periodic two-dimensional roughness consisting of 0.014" (0.0356 cm.) high ridges ("teeth") running perpendicular to the flow vector. The Reynolds number based on this roughness height exceeds the one considered adequate for de-stabilizing the boundary layer, as was already discovered in the first year (1980-81) of the research. In addition to the rough-surface insert, a smooth-surface insert was also made for tare measurements.

A thorough flow-field study was completed for both the smooth and the rough surfaces, with the aim of deducing the dependence of the boundary layer profile shape, layer kinematic and momentum thicknesses and momentum Reynolds number on the stagnation pressure and distance x from the leading edge. The test conditions were supply pressures of 600, 475, and 350 mm. Hg., temperatures of 100° F. and 125° F. and a fixed stream Mach number of 3, producing unit Reynolds numbers of 33,000, 46,000, and 58,000 cm^{-1}. The measurements consisted of surface pressures, surface temperatures, and 65 pitot-tube profiles from the leading edge to the transition zone (roughly $0 < x < 15$ cm.).

The results of the flowfield measurements, which are essential for the study of the stability were:

1. Transition to turbulence, which begins at 9 x 12 cm. for the

smooth wall ($460 < Re_\theta < 600$), begins earlier for the rough wall ($8 < x < 10$ cm., $370 < Re_\theta < 530$), the variations quoted here denoting a unit-Reynolds-number effect. (Figure 1)

2. The laminar boundary layer over the smooth wall is in very good agreement with theoretical (Blasius) expectations. (Figure 2)

3. The flow over the rough-wall ridges is of the skimming type; i.e. the cavities formed by the teeth are closed. (Figure 3)

4. The velocity profiles of the rough-wall boundary layer are surprisingly similar to those over the smooth wall, a result previously reported for randomly-rough walls at low speeds. The differences are too small to reveal a systematic effect of the roughness, although the latter generally tends to decelerate the flow near the wall. (Figures 4 and 5)

The dual observation of transition enhancement by the roughness, and the very feeble effect of the latter on the profile, means that for roughness heights exceeding the critical, the boundary layer stability is very sensitive to roughness. In turn, this means that there will be some difficulty in attributing observed instabilities to a particular profile distortion -- not an uncommon occurrence in tests of this type.

About half of the final stability data with the hot-wire anemometer, those pertaining to the rough wall, were also obtained during this period. For each of the three fixed supply pressures, a 0.00002"-dia. hot-wire anemometer was held fixed in the boundary layer at each of about 70 equally spaced positions, from the leading edge to near the end of the flat plate model (3 x 70 = 210 points total).

Ten-second "bursts" of hot-wire signals were recorded on analog tape at each position. In addition, a second group of data was recorded which was identical to that obtained in the layer, except that the second group was obtained in the free stream along a line parallel to the surface, and located about 4 boundary layer thicknesses above the latter.

The hot-wire data just mentioned constitute the main measurements of this research, and their analysis is expected to occupy the current (final) year of this grant. In the meantime, however, tentative examination of these data, examples of which are shown on Figure 6, showed ample evidence that hydrodynamic stability is at work in the rough-surface boundary layer. Stability theory predicts a region of damped disturbances at low Reynolds numbers (small x), followed by a high-frequency amplification regime which is in turn followed by low-frequencyamplification. A series of power spectra taken along increasing x would thus show an initial uniform decrease of the spectrum followed by spectra with a "hump" at mid-frequencies and eventually by a spectrum monotonically decreasing with frequency. This sequence of events indeed appears on Figure 6.

The following work is planned or 1983-1984:

a. Measurement of the stability of the smooth (tare) surface with the hot-wire, in a manner analogous to that shown on Figure 6 for the rough wall.

b. Reduction of the smooth-wall and rough-wall hot-wire data to uncover differences in amplification factors, and in the dependence of the stability diagram on roughness.

c. Comparison with smooth-wall supersonic stability data obtained elsewhere.

d. Similar reduction of the data obtained in the free stream, to see to what extent the stream turbulence affects either the smooth- or the rough-wall stability.

e. Quantitative measurement of the stream turbulence.

VELOCITY @ 350 FOR SMOOTH (LEFT) AND ROUGH (RIGHT)

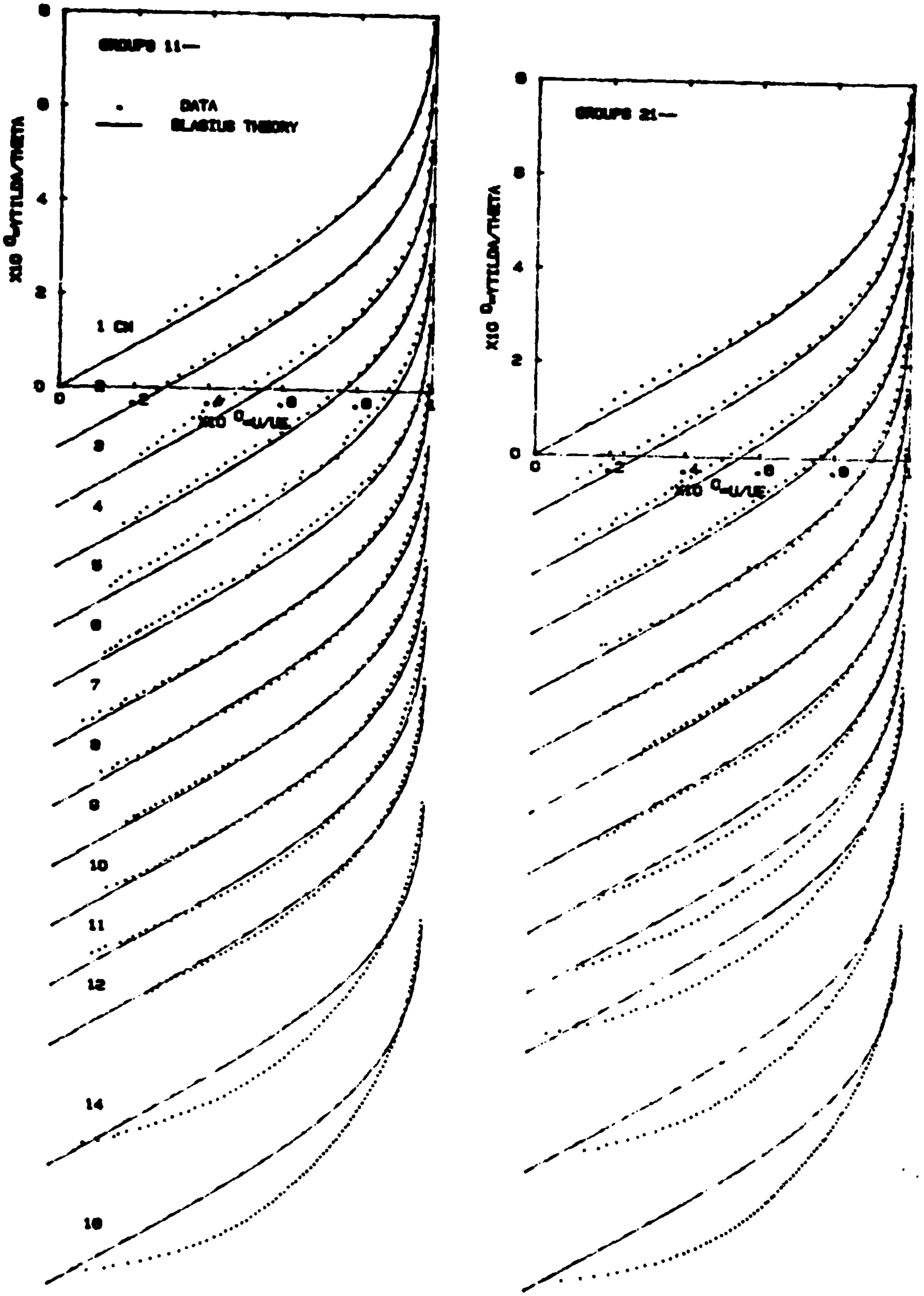

Figure 1. Transition to turbulence in these velocity profiles is indicated by the departure of the data (points) from the laminar flow flow theory (solid lines) at the inicated distance (in cm.) from the L.E.

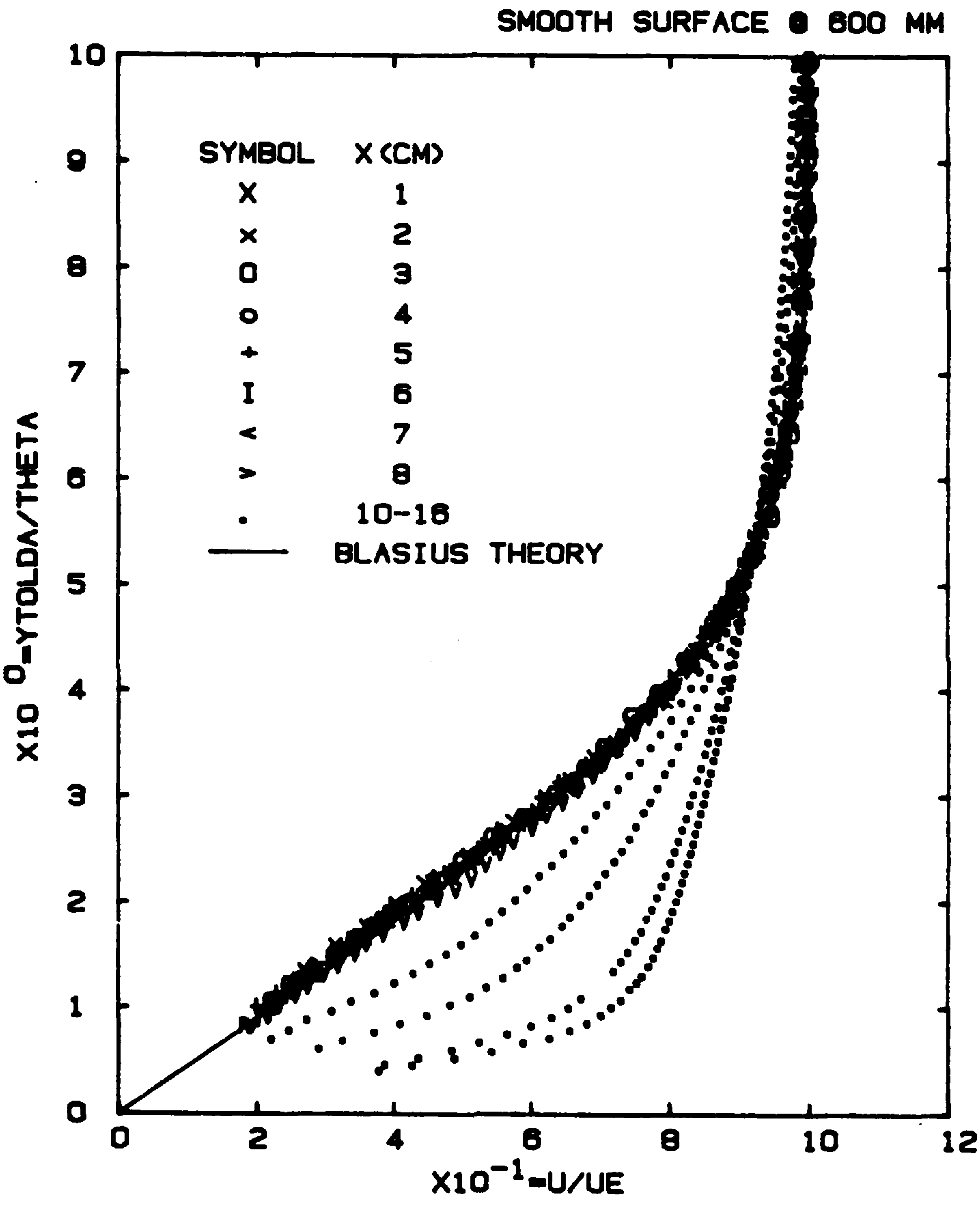

Figure 2. Comparison of measured boundary-layer velocity profiles with theory. Profile points beyond 10 cm demcnstrate transition to turbulence.

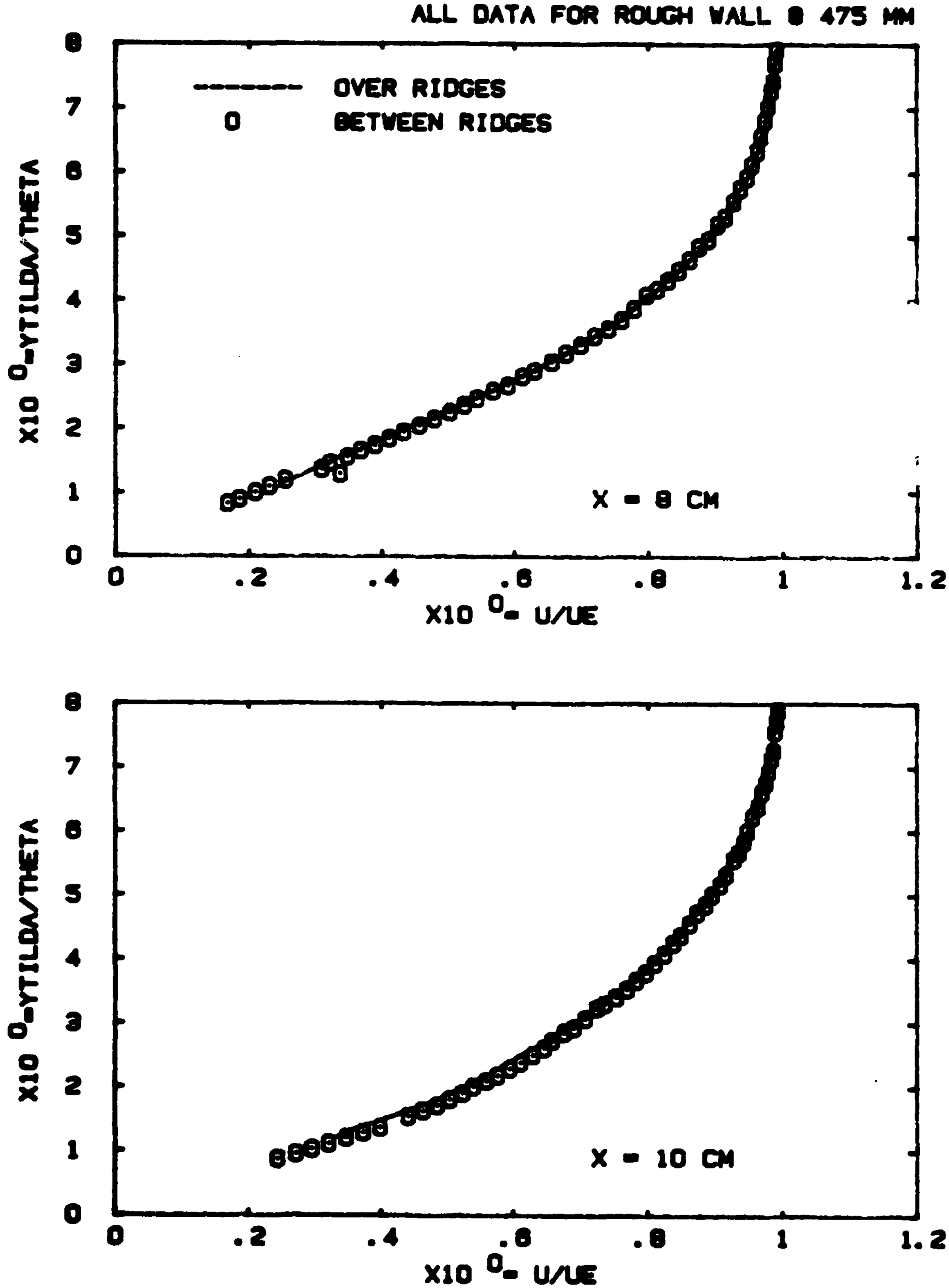

Figure 3. Velocity profiles taken over the "valleys" between ridges and those taken over the ridges themselves are identical, showing that the flow "skims" over the ridges and that the cavities are "open".

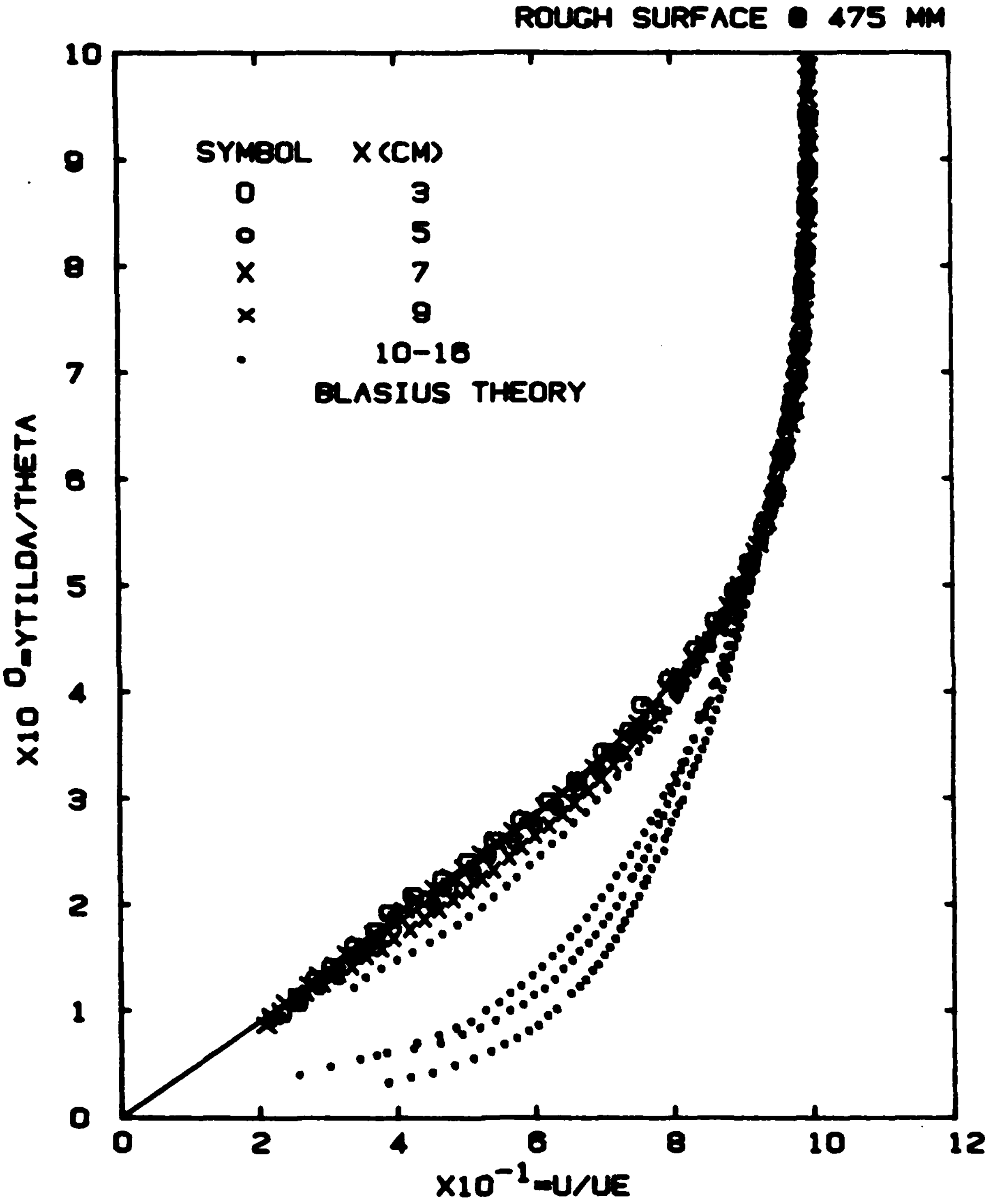

Figure 4. Velocity profiles over the rough wall show very little difference from the theoretical (Blasius) profiles.

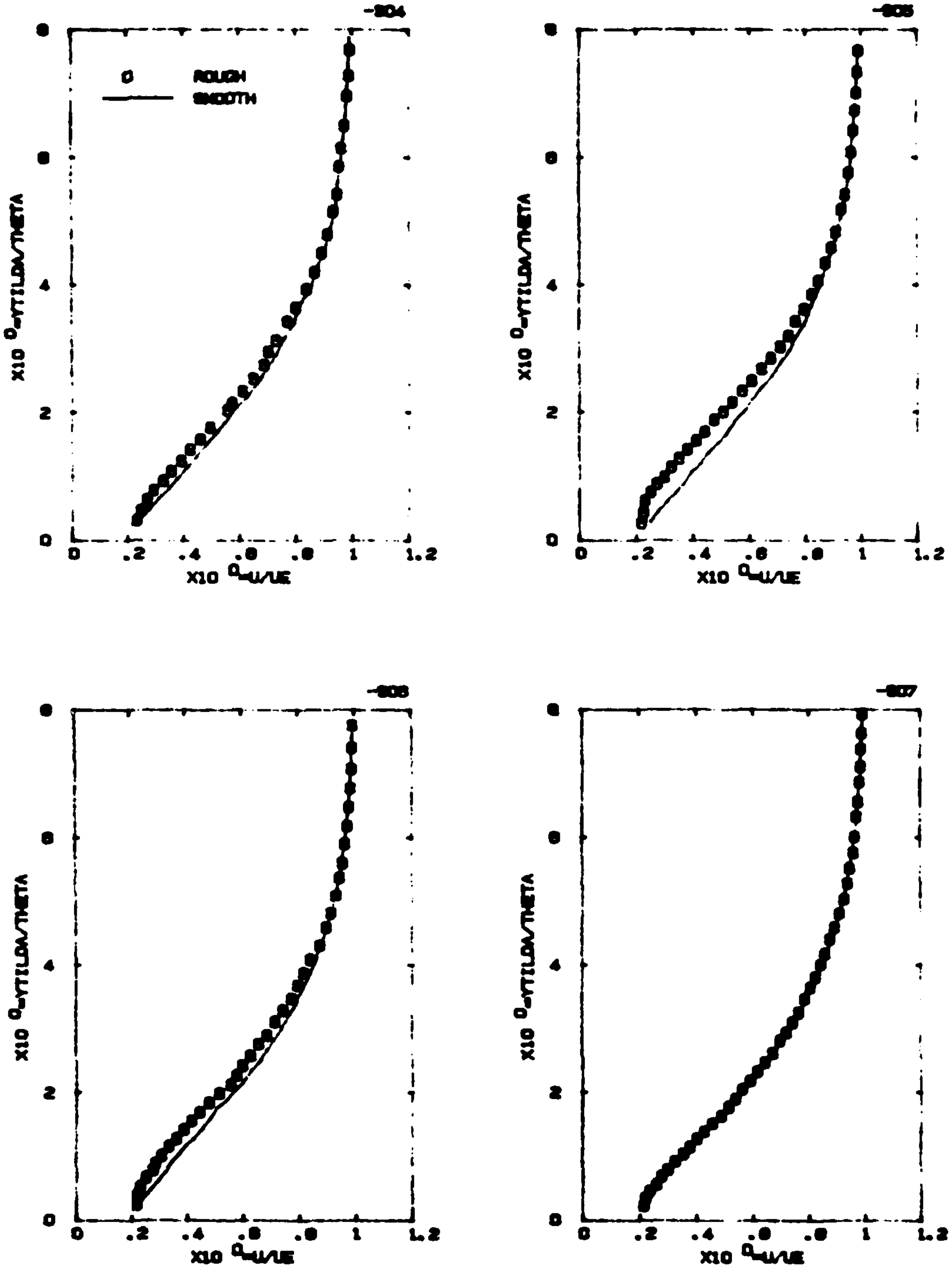

Figure 5. Comparison of the rough-wall and smooth-wall velocity profiles shows a small difference indicating that the roughness generally decelerates the boundary-layer flow.

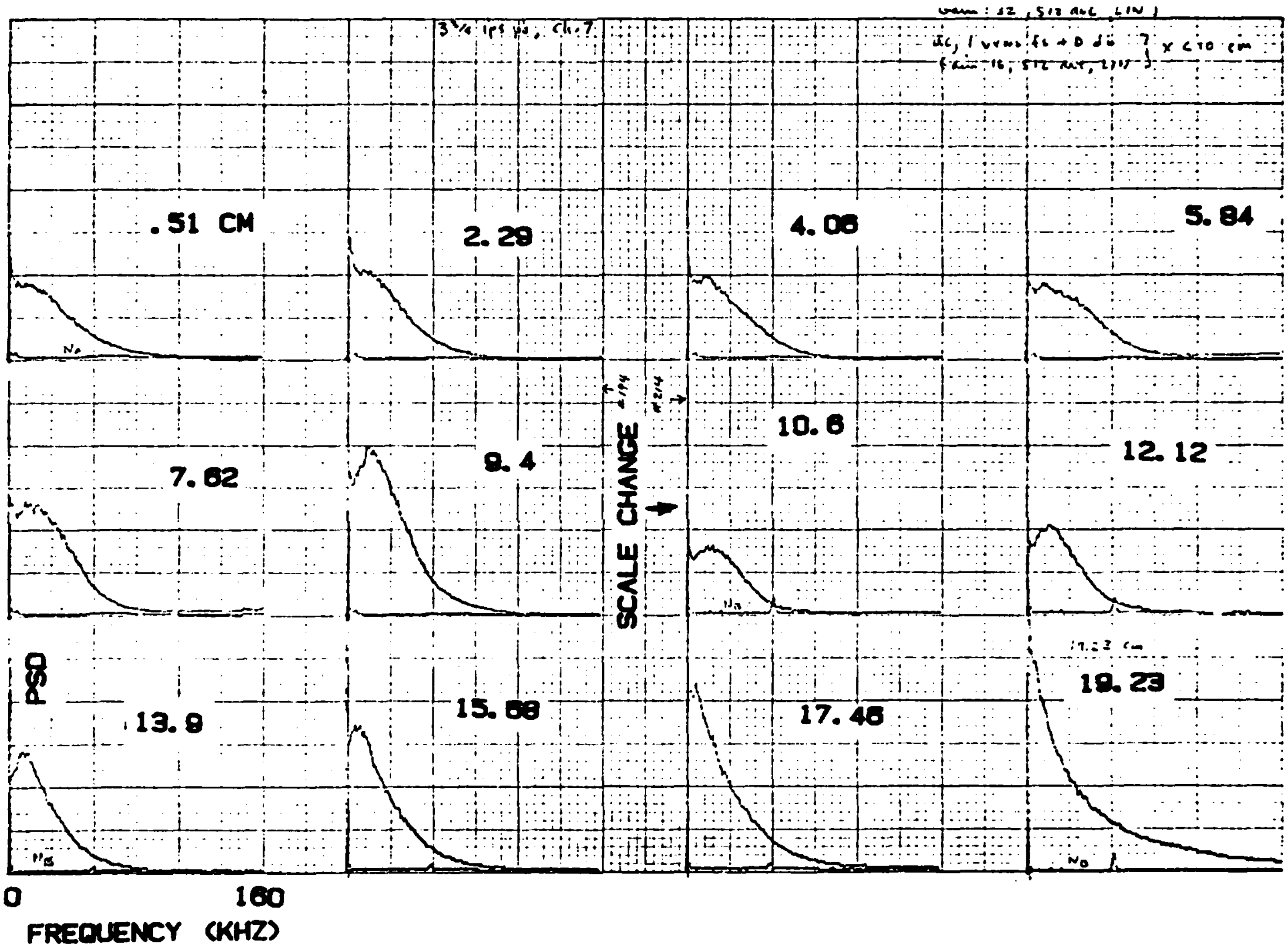

Figure 6. Spectra measured from the stored hot-wire data at the distances from the leading edge indicated, show that the rough-wall boundary layer may be subject to the familiar sausage-shaped instability region of the Reynolds-no.-vs-frequency plot. This is implied by the damping at all frequencies evident before x=5.8 cm, the appearence of a spectral "peak" between 7 and 14 cm, and the eventual monotonic spectrum toward the end of the plate (x=19.2 cm).